# *DC Power for Improved Data Center Efficiency*

**EXECUTIVE SUMMARY**

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The work described in this report was performed as part of Lawrence Berkeley National Laboratory's (LBNL) "High-Performance High-Tech Buildings" project focused on improving energy efficiency in Laboratory, Cleanroom, and Data Center facilities. This project was sponsored by the California Energy Commission's Public Interest Energy Research (PIER) Industrial program with technical leadership by LBNL. Ecos Consulting and EPRI Solutions performed the research reported herein collaboratively under subcontract to LBNL and with input from industry advisors and manufacturers.

# 1. Executive Summary

## 1.1 Introduction

The mission of data centers in use today calls for them to be much more energy intensive than other office buildings. Recent reports prepared by this project team for the California Energy Commission estimated that the US annual energy consumption by the equipment in these centers can use up to 14.6 TWh, with supporting equipment such as uninterruptible power supplies (UPS) accounting for up to 7.1 TWh. The data center market represents an important component of the California economy as well as a considerable and growing source of electrical demand. Preliminary investigations confirmed that research with the objective of improving the efficiency of data center was warranted.

Typical data center power delivery designs use AC (alternating current) power, distributed to the facility at 600V AC or 480V AC. This AC power is then stepped down to 208V AC or 120V AC for distribution to racks for use by servers and other information technology (IT) equipment. An UPS and energy storage system, such as batteries or flywheels is used to isolate equipment from power interruptions or other disturbances. This set up generally involves converting incoming AC power to DC (direct current) for energy storage. The DC power is then converted back to AC for the facility distribution grid and routed to power distribution units (PDUs) for distribution to equipment in racks.

Inside the servers and other IT equipment such as storage or networking units, power supplies convert AC (at 208/120V AC) to DC voltage needed for the digital electronics. Power supplies usually provide power factor correction as well as load isolation from the incoming power line for these sensitive electronic components. Thus, there can be up to six or more power conversion stages between facility power entry and the microprocessor or other data processing circuits.

The power losses due to the use of inefficient power conversion devices from both outside and within equipment result in a large loss of useful electrical power, as well as directly increasing the energy required to remove the heat produced. Thus, for every watt of power utilized to process data, about 0.9W is required to support power conversion. In addition, about 0.6 to 1 watt will be required to cool the power conversion equipment.

This report details a demonstration of alternative approaches for delivering power to computational and network equipment in a data center using DC, and comparing its efficiency to the more traditional approach using AC.

## 1.2 Project Objectives

The objectives of this demonstration project are to develop and demonstrate a power delivery system that does not contain as many power conversion stages using existing equipment and vendors where possible.

This project implemented a power delivery system that distributes DC to the server racks. The system used a single rectification stage, thereby removing the conventional UPS, transformer, and the rectifier in the server's first stage power supply. A standard AC distribution system is installed next to this DC system, server loads were connected and programmed to run identical routines. For this identical amount of computing work, the input power for whole system was measured and compared.

The following goals were identified for this demonstration project:
1. Show that DC-powered server(s) exists in the same form factor or can be built.
2. Show that DC-powered server(s) provides the same level of functionality.
3. Measure and document any efficiency gains from the elimination of multiple conversion steps in the delivery of DC power to the server hardware.
4. Identify areas requiring further development or follow up investigations.

## 1.3 Project Implementation

As part of the previous server power supplies and UPS work, the project team identified a number of industry stakeholders and held discussions with them regarding participation in a possible demonstration of an integrated DC power delivery system.

In early 2006, a suitable location for the demonstration project was found in Newark, CA. The project participants also helped to define the three configurations for the demonstration project. They are:

- **AC Reference Configuration**: This configuration is needed to simulate current data center typical set-up, delivering 208/120V AC input to AC-powered servers, and to be used as a reference to compare conversion efficiency.
- **Facility-Level DC Configuration**: This configuration is needed as the proof of concept – the ability to deliver high-voltage DC throughout the facility. This configuration handles the DC conversion/distribution at the building/data center level, converting 480V AC to 380V DC and delivering this directly to the DC-powered server units in the rack.
- **Rack-Level DC Configuration**: This configuration is needed to provide a possible migration option for AC data centers operators wishing to use DC equipment without facility-wide DC power distribution. This configuration accomplishes DC conversion/distribution at the rack level, using a rectifier unit to convert 208/120V AC at the rack, and delivering 380V DC to DC-powered servers.

In addition, a number of conditions were agreed upon by the participants and the project team on implementation, including:

- **Testing and Measurements**: The group agreed on test points and metrics, with emphasis on measuring the efficiency of the configurations – there would be no direct comparison of server equipment performance.
- **DC Input Voltage**: Due to compatibility with existing equipment and devices, the group settled on 380 V DC for the high voltage DC input.

Project participants contributed time, equipment, in kind services or input towards project implementation. The demonstration set up as defined was completed by mid June 2006, and demonstrated to the press and other industry representatives on June 21. A series of "open houses" were held through out the months of July and August. Over 200 visitors attended these demonstrations.

The interest generated by the project helped to bring about other manufacturers of DC equipment, notably manufacturers of communication and support equipment using 48 V DC. These manufacturers provided additional computing and telecommunication equipment for the use of the demonstration project. The presence of this equipment provided another reminder that DC power distribution is not new, and has been safely and effectively used in telecommunication and data networks. In addition, it also showed that DC and AC power delivery system can co-locate in a data center facility.

## 1.4 Project Results

Our results indicate that the DC approach does provide an increase in conversion efficiency. We were fortunate enough to have access to two AC distribution systems as well as two DC conversion/distribution systems, and the efficiency ratios were determined for both sets.

**Table ES1**

| System Efficiency | UPS Efficiency | Transformer Efficiency | PS Efficiency | System Efficiency |
|---|---|---|---|---|
| AC System A: Measured Efficiency | 90% | 98% | 90% | 79% |
| AC System B: Measured Efficiency | 90% | 98% | 90% | 79% |
| DC System A: Measured Efficiency | 94% | 100% | 92% | 87% |

| Energy Consumption | Compute Load (kWh) | Input Load (kWh) | Efficiency Gain |
|---|---|---|---|
| AC System A: Measured Consumption | 23.3 | 26.0 | |
| AC System B: Measured Consumption | 23.3 | 25.9 | |
| DC System A: Measured Consumption | 22.7 | 24.1 | |
| **% Energy Consumption Improvement vs. AC System A** | | | **7.3%** |
| **% Energy Consumption Improvement vs. AC System B** | | | **7.0%** |

It can be seen (Table ES1) that there is about a 7% decrease in input energy using the first DC system compared to the "best in class" AC systems. With the second DC system, the values are slightly lower, but still about 5% improved over the AC systems (Table ES2).

**Table ES2**

| System Efficiency | UPS Efficiency | Transformer Efficiency | PS Efficiency | System Efficiency |
|---|---|---|---|---|
| AC System A: Measured Efficiency | 90% | 98% | 90% | 79% |
| AC System B: Measured Efficiency | 90% | 98% | 90% | 79% |
| DC System B: Measured Efficiency | 92% | 100% | 92% | 85% |

| Energy Consumption | Compute Load (kWh) | Input Load (kWh) | Efficiency Gain |
|---|---|---|---|
| AC System A: Measured Consumption | 23.3 | 26.0 | |
| AC System B: Measured Consumption | 23.3 | 25.9 | |
| DC System B: Measured Consumption | 22.7 | 24.6 | |
| **% Energy Consumption Improvement vs. AC System A** | | | **5.0%** |
| **% Energy Consumption Improvement vs. AC System B** | | | **4.7%** |

It should be noted that both of the AC distribution system used represent the best on the market with regard to efficiency. Both of the AC UPSs are high efficiency units, and the efficiencies of the power supplies in the AC servers – at 90%, are much higher than units currently found in today's data centers. By comparison, a typical AC system in today's data center would have a UPS that was about 85% efficient, and power supplies around 73% efficient.[1] The estimated improvement of the DC system over these "typical" systems is shown in Table ES3 below.

**Table ES3**

| System Efficiency | UPS Efficiency | Transformer Efficiency | PS Efficiency | System Efficiency |
|---|---|---|---|---|
| AC Typical Distribution Efficiency | 85% | 98% | 73% | 61% |
| DC Distribution Efficiency | 92% | 100% | 92% | 85% |

| Energy Consumption | Compute Load (W) | Input Load (W) | Efficiency Gain |
|---|---|---|---|
| Typical AC Distribution Efficiency | 10,000 | 16,445 | |
| DC Distribution Option (Optimized) | 10,000 | 11,815 | |
| **% Energy Consumption Improvement vs. Typical AC Distribution** | | | **28.2%** |

In this case, an improvement of over 28% is possible in an average data center. This means the DC distribution system, as demonstrated, will have the potential of using 28% less energy than the typical AC system found in today's data centers. Since data center HVAC loads are typically about the same as the IT load, this means that a 28% improvement in distribution and conversion also means a 28% overall facility level efficiency improvement.

It should be noted that the magnitude of the DC efficiency gain is highly dependent on the AC reference system and AC/DC power supply that it is being compared to. However, exposing the industry to "best in class" systems may also be useful in bringing attention to the need for improving the average efficiency of data centers.

## 1.5 Conclusions and Recommendations

This demonstration project was able to coordinate the participation of 21 organizations, their equipment, and/or in kind contribution, worked with other organizations' input throughout the implementation process, and assembled equipment and services worth over a million dollars in value. We were also able to conclusively demonstrate to the data center industry (via the 200+ open house attendees and the media coverage) that DC delivery systems are viable, can be 20% or more efficient than current AC delivery systems, be more reliable, and potentially cost less in the long run.

Overall, the project succeeded in meeting the objectives that were set out at the beginning. In particular:

**Availability of DC Equipment**: The demonstration project showed that DC-powered servers exist in the same form factor as AC servers or can be built and operated from existing components with minimal effort. DC servers currently exist (in the 48V DC form

[1] These are typical numbers that were found in our evaluation of the servers and UPSs markets.

factors), but 380V DC servers and storage equipment could be built and operated from existing components. Further, the demonstration project gave visibility to the DC power conversion and distribution equipment, highlighting two commercially available rectification systems, as well as UL-listed buss bars for DC applications.

**DC Functionality**: The project also showed that DC-powered servers can provide the same level of functionality and computing performance when compared to similarly configured and operating server containing AC power supplies. The demonstration equipment included storage units as well as DC network equipment that can use a variety of DC voltages.

**Demonstrated Gains in Efficiency**: The project demonstrated clear efficiency gains from the elimination of multiple conversion steps in the delivery of DC power to the server hardware. Results were measured and documented from two sets of DC delivery systems, and compared to two sets of AC delivery systems. In both cases, the DC delivery system showed a minimum of 5% to 7% efficiency gains without significant optimization over two AC distribution systems that are "best in class" and much more efficient than most systems found in today's data centers. These measured efficiency gains did not include additional gains from a reduction in cooling loads, which can have the potential for additional savings. Raising awareness of the AC - UPS system efficiency will have a benefit even if the DC solution is not embraced.

**Follow-Up Investigations**: A number of areas for follow up investigations were identified that will help generate industry discussions, and provide useful leverage points to move the industry forward in the direction of DC distribution. These include:

- **Grounding, Protection and Overloading Prevention**: A number of grounding, protection and overload prevention practices for DC data centers are discussed in this report for industry considerations.
- **Reliability**: Anecdotal data shows that DC-powered data centers have the potential to be more reliable than AC-powered data centers. However, data does not exist for DC voltages higher than 48V DC. Leadership will need to come from the industry in adoption or additional testing for the industry to move forward on this area.
- **Costs**: While cost data exists, it has not yet been compiled in a way that direct comparisons can be made for the two distribution systems (or their TCO). The demonstration has generated significant interests from data center designers and system integrators, and further discussion on this area can lead to at least a first-order estimate of DC distribution costs. A related area is the costs of DC components vs. AC components. Currently, AC components may enjoy better economies of scale, but wide-spread DC power adoption may change this equation.
- **Integration with Other Sources**: The use of DC in data center can also simplify the integration of alternative energy sources, such as solar and other forms of renewable energy, as well as fuel cells and distributed generation, which are all DC-based.
- **Other Issues**: Of significant concerns is the lack of industry knowledge of the advantages of DC distribution, as well as misconceptions about DC power. Additional education and outreach efforts will be required if the energy savings potentials of DC powered data centers are to be realized.

Going forward, there remain many barriers to the adoption of DC power distribution, and need additional follow on work. In particular, a number of barriers have been identified during the course of this projects, they include:

- **Increasing Awareness of DC Distribution**: The industry's current knowledge of available options for efficiency and DC distribution is quite low. Further, there is no single, trusted source of information, or an entity dedicated to the promotion of data center energy-efficiency and DC distribution (other than the CEC/PIER efforts). With the current industry support and interest, a "DC Power" association of some sort will help to focus interest and help to elevate awareness among the data center market.
- **Creating a Market for DC**: A number of market barriers still need to be addressed in a consistent, unified manner. Coordinating utilities and other efforts, at least in California, will go far towards getting DC approaches to take hold in the data center market. There is utility interest in establishing a baseline of performance and cost, which can then help to address at least the early adoption barrier of cost. Other efforts are still needed, and strategies to address market transformation used by the conservation movement can be directly applied here. In addition, the US Congress has recognized the potential for energy savings with HR-5646, so that coordination with DOE and EPA is needed to ensure no duplication of efforts.
- **Develop standards to accelerate adoption**: Agreement on distribution voltages, electrical connectors, grounding, DC power quality, and other issues will be important to enable the market to adopt DC distribution on a large scale. The PIER program should facilitate these efforts by bringing together the appropriate industry representatives.
- **Developing Pilot Projects**: Once the Demonstration Project was completed, there are no other places where such a set up can be found. Efforts are needed to continue the Demonstration Project's role in informing the industry of the DC distribution alternative. Discussions are underway with a number of "early adopters," and the project team proposes to establish several pilot projects to:
    - Create demand for DC servers to enable certification efforts to proceed
    - Determine cost factors for DC systems - capital and operating cost
    - Evaluate and resolve any remaining barriers
    - Publicize successful systems in real data centers.

Additional information can be found on line at:

http://hightech.lbl.gov/dc-powering

# Appendix A: Project Participants

### Participants List

#### Project Organizers

- Lawrence Berkeley National Laboratory: William Tschudi, Evan Mills, Jon Koomey, Steve Greenberg
- Ecos Consulting: My Ton
- EPRI Solutions: Brian Fortenbery

#### Industry Partners

- Alindeska Electrical Contractors
- AMD
- APC
- ANCIS Inc.
- Baldwin Technologies
- CCG Facilities
- California Energy Commission
- Cingular Wireless
- Cisco Systems
- Cupertino Electric
- Data Power Design
- Dell
- Dranetz-BMI
- Dupont Fabros
- EDG2
- Emerson Network Power
- EYP Mission Critical Facilities
- Fairchild Semiconductors
- Gannett
- HP
- IBM
- IEM (Industrial Electric Manufacturing)
- Intel
- Morrison Hershfield
- Nextek Power Systems
- NTT Facilities
- Panduit Corp.
- Pentadyne
- Rosendin Electric
- RTKL
- Rackable Systems
- SatCon Power Systems
- SBC Global
- Solara
- Square D
- Sun Microsystems
- 380voltsDC.com
- TDI Power
- Universal Electric
- Verizon Wireless
- Visa